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ScienceDirect
Neuroscience Research 58 (2007) 265–271
Neuroscience Research
www.elsevier.com/locate/neures

# Muscle activities are differently modulated between masseter and neck muscle during sleep–wake cycles in guinea pigs

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Received 28 July 2006; accepted 22 March 2007
Available online 28 March 2007

**Abstract**

Sleep bruxism is a sleep-related movement disorder characterized by an exaggerated jaw motor activity during sleep. Currently, the magnitude of jaw motor activation in normal sleep remains poorly understood. In this study, we aim to assess the state-dependent changes in the magnitude of electromyographic activities of the jaw-closing masseter muscle in comparison with those of a neck muscle (specifically, the obliquus capitis) during sleep–wake cycles in guinea pigs. These electromyographic activities were integrated for 10-s epochs during wakefulness, non-rapid eye movement (NREM) and rapid eye movement (REM) sleep. The masseter activity per epoch was found to be five times lower in both sleep stages while the neck muscle activity also decreased to 30% in NREM sleep and was lowest (16%) in REM sleep. In the periods without motor activity, masseter tone did not differ between the three states, whereas neck muscle tone decreased from wakefulness to NREM sleep and further to REM sleep. Moreover, in the epochs with masseter activation, the neck muscle activity did not increase during sleep. These results suggest that masseter activity decreases but is occasionally activated during sleep, and that state-dependent changes in electromyographic activity can be differently modulated in time and intensity between the masseter and the obliquus capitis.


*Keywords:* Sleep–wake cycles; Masseter; Neck muscle; EMG; Sleep bruxism; Sleep-related movement disorders

## 1. Introduction

Sleep studies in humans have shown that phasic and tonic muscle bursts in the body occasionally occur during sleep (Townsend et al., 1975; Pollmächer and Schulz, 1993; Lavigne et al., 2001; Kato et al., 2004). Motor activities or movements during sleep range from a very simple activity localized in one or a few segments to more complex movements involving the entire body (Hening, 2003). Although various types of motor activities are observed during sleep in normal subjects, the conditions can be regarded as sleep-related movement disorders if the occurrence of these motor activities is sufficiently exaggerated to disturb sleep or to result in undesirable consequences to one's health (AASM, 2005).

This is also the case in jaw muscles. An exaggerated form of jaw-closing muscle activity occurs in patients with sleep bruxism. Since the increased muscle work activity in jaw-closing muscles is thought to be associated with undesirable orodental problems such as tooth wear, fracture of dental prostheses and orofacial pain problems (Lavigne et al., 2005), many studies have been carried out to characterize jaw-closing muscle activities during sleep in humans. Jaw-closing muscles are activated during sleep even in normal subjects although the magnitude of muscle activities becomes lower than during wakefulness (Miyamoto et al., 1996; Gallo et al., 1999; Lavigne et al., 2001; Saifuddin et al., 2001; Baba et al., 2005). Compared with normal subjects, patients with sleep bruxism have a similar level of masseter tone during sleep although they exhibit an increased number and intensity of jaw-closing muscle episodes (Macaluso et al., 1998; Lavigne et al., 2001; Kato et al., 2003a; Huynh et al., 2006). The underlying neurophysiological mechanisms in the genesis of jaw-closing electromyographic activity remain to be clarified (Lavigne et al., 2003; Kato et al., 2003b).

Very few studies have been performed to quantify the electromyographic activity of jaw-closing muscles during sleep

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0168-0102/$ – see front matter 
doi:10.1016/j.neures.2007.03.008

in animals. Recent studies have observed periods of high and low jaw-closing activities 24-h a day (Langenbach et al., 2004; Grünheid et al., 2005). Since several studies have reported that trigeminal motoneuron excitability decreases during sleep (Chase et al., 1980; Inoue et al., 1999), the periods with lower jaw muscle activities can be associated with sleep. In addition, another study showed the different state-dependent changes between tongue muscle and neck muscle, the latter of which is commonly used as an index of motor activity during sleep–wake cycles in animals (Lu et al., 2005). This suggests that motor control during sleep–wake cycles differs between muscles in the body segments. Based on these findings, we hypothesized that masseter activity decreases during sleep and that masseter activity is differently modulated during sleep–wake cycles compared with neck muscle activity. Then, we assessed the magnitude of electoromyogram (EMG) activity of the jaw-closing muscle (masseter) and neck muscle (obliquus capitis) during sleep–wake cycles and compared the state-dependent changes between the two muscles. To do these analyses, electromyographic activities of the masseter and obliquus capitis were recorded simultaneously with sleep variables in freely moving guinea pigs. The guinea pig was chosen as an experimental animal because these animals are often used for investigating the physiology of sleep and trigeminal motor systems (Byrd, 1981; Goldberg et al., 1982; Nozaki et al., 1986; Escudero and Vidal, 1996; Edeline et al., 2001; Zhang et al., 2003; Pedemonte et al., 2005).

## 2. Materials and methods

### 2.1. Surgical implantation

Seven adult albino guinea pigs (Hartley), weighing 300–450 g, were prepared for chronic recording of electroencephalogram (EEG), electro-occulogram (EOG), electrocardiogram (ECG), and electromyogram (EMG) activities of neck and jaw-closing muscles. Surgery was performed under sodium pentobarbital anesthesia (40 mg/kg, i.p.) premedicated with atropine (0.04 mg/kg, i.p.). Five T shaped stainless steel screws (diameter: 1.4 mm) were implanted in the skull: two screws for EEG were placed over the frontal cortex, another two in the right orbital bone for EOG, and one in the occipital bone for the ground. Urethane-coated stainless steel wires (diameter: 0.05 mm) were soldered to the implanted screws before surgery. Two pairs of wires were inserted in the obliquus capitis and in the left masseter. For ECG recording, a pair of stainless wires were inserted into the right and left sides of the rib cage. The wires for EEG, EOG, ECG and EMGs were soldered to a multiple pin socket in the connectors. The connectors were fixed to the skull with dental acrylic resin. Antibiotic ointment (gentamycin sulfate) was applied around the wound and an antibiotic (oxytetracycline, 10 mg/kg) was injected intraperitoneally for 3 days following surgery. The experiment protocols were approved by the animal research ethics committee of the Matsumoto Dental University.

### 2.2. Recording procedures

Animals were housed in cages in a room with LD 12:12 cycles (light period: 06:00–18:00 h). During the recovery period, the animals were made to adapt to the acrylic recording chamber for 3–5 h for at least 3 separate days, with the recording cable connected. Recording sessions were started 1 week after postoperative recovery. An animal was placed in the recording chamber and was allowed to feed freely. Polygraphic recordings were made for 3 h during a light period (12:00–15:00 h). Although the circadian effect on sleep–wake rhythm has been reported to be weak in guinea pigs, the recording during this period can allow us to assess EMG activity during the sleep–wake cycle with least circadian influence (Tobler et al., 1993; Ibuka, 1984). The recordings were amplified (AB-621G, NIHON-KODEN, Japan) with optimal bandwidths (EEG, EOG and ECG: 0.3–100 Hz; EMGs: 100–1000 Hz), and the results were fed continuously into a personal computer using a commercial program (SleepSign, KISSEI COMTEC Ltd.) with a sampling rate of 512 Hz for all channels. Operationally, the same sampling rate should be chosen for all recording channels in the software used to obtain delta EEG spectral power with an optimal resolution for the off-line scoring of the vigilance states. The sampling rate, lower than twice as fast as the highest frequency component, was used in a previous study to assess the relative magnitude of EMG activity (Lu et al., 2005). The animals' behavior was simultaneously video taped for analysis.

### 2.3. Scoring states of vigilance

The states of vigilance (e.g., wakefulness, non-rapid eye movement [NREM] sleep and rapid eye movement [REM] sleep) were determined for

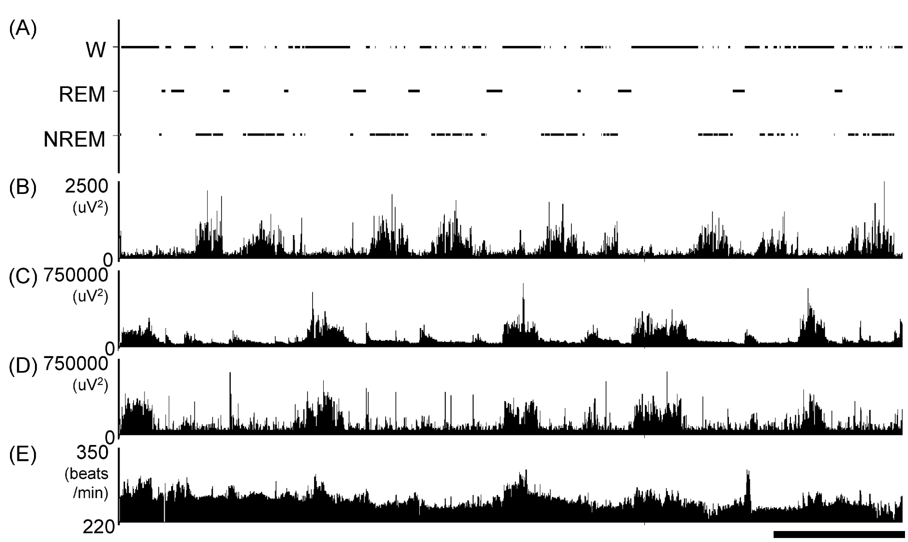


Fig. 1. Distribution of vigilant states and corresponding activities of EEG, EMG, and cardiac measures. (A) Sleep periods usually started with NREM sleep (NREM) followed by REM sleep (REM). Delta power (B), integrated EMG activities of the masseter (C) and the neck muscle (D) and mean heart rate (E) showed changes correlating to vigilance states. The spectral power of delta EEG activity (B) was high during NREM sleep while the EMG activities of the masseter and the neck muscles were high during wakefulness (W). Mean heart rate per epoch was low during NREM sleep. Sleep–wake cycles occurred several times. The horizontal bar: 30 min.